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BENEFITS ESTIMATION FOR SIMULATION SYSTEMS USED FOR AIRCREW TRAINING IN A MULTISHIP ENVIRONMENT

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A general model for the benefit evaluation of multiship training simulation systems is presented. The benefit measures derived are oriented toward allowing benefit-cost evaluations of proposed alternative simulation systems. The model is based on empirical data drawn from evaluation studies of simulators as well as analytical approaches. The focus of the approach using this model is selecting the most appropriate and economic simulators for use at the operational level. The model does not attempt to compare, or justify the comparison of, the training value of a specific simulator versus a specific aircraft. The model allows for full sensitivity analysis and variation of all important parameters. A set of LOTUS 1-2-3 spreadsheets are presented which facilitate the use of the model. The model is demonstrated by means of an application which is based on actual data.

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CONTENTS

	Page
INTRODUCTION	1
BACKGROUND	2
BASIS FOR BENEFITS COMPUTATION	6
PERFORMANCE AREAS	9
DETERMINATION OF NUSE AND CUSE VALUES	13
DETERMINATION OF ESIM VALUES	16
COMPUTING THE NUMBER OF TRAINING REPETITIONS	18
COMPUTING NUMBER OF SIMULATION SORTIES	19
ESTIMATION OF BENEFIT CONVERSION FACTORS	21
BENEFITS COMPUTATION MODEL	22
TEST OF THE BENEFITS COMPUTATION PROCEDURE	22
CONCLUSIONS AND RECOMMENDATIONS	30
REFERENCES	36

FIGURES

Figure No.		Page
1	Flowchart of Benefits Computation	5
2	Isoutility Curve Illustrating Pilot Training Under Current Training Conditions	7
3	Isoutility Curve Illustrating Pilot Training Under "New" Training Conditions	8
4	The Air Intercept Trainer (AIT)	28

TABLES

Table No.		Page
1	Variable Identification and Definition	3
2	F-15 Combat Tasks (Basis for Performance Areas)	10
3	Selection of Performance Areas Instructions and Measurement Scale	13
4	Selection of Relative Weights of Performance Areas	14
5	Determination of CUSE and NUSE Values	17
6	Acquisition of ESIM Values	18
7	Data Spreadsheet (NUMCALC) to Compute Number of Simulation Sorties	20
8	Spreadsheet (NEWBEN.WK1) Showing Method for Computing Benefits	23
9	Performance Areas Selected for AIT Evaluation	29
10	Relative Time To Be Spent Training Each Performance Area	30
11	Total Number of Simulation Sorties - AIT Test Case	31
12	ESIM Values for the AIT Example Case	32
13	Benefits Computation Results for the AIT Test Case	33

PREFACE

The research described in this report was conducted at the Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division (AL/HRA), in Mesa, Arizona, under Work Unit 1123-05-01, In-House Research and Development Support.

In 1990, Dr William C. Moor of Arizona State University, working in conjunction with Dr Dee H. Andrews and other AL/HRA personnel, developed a preliminary model for the benefit-cost evaluation of multiship simulator alternatives. This report is an effort to improve the definitions and use of some of the variables required by this model.

BENEFITS ESTIMATION FOR SIMULATION SYSTEMS USED FOR AIRCREW TRAINING IN A MULTISHIP ENVIRONMENT

INTRODUCTION

Many efforts have been made to determine the "value" of aircraft simulators for training military pilots (Barcus & Barcus, 1986; Lethert, 1985; and Orlansky & String, 1982). While none of these could be deemed a failure, neither are any regarded as wholly successful or suitable for the comparison of different simulators intended for the same purpose.

The U.S. Air Force (USAF) desires, insofar as possible, that proposed capital expenditures be based on a benefit-cost comparison among all competing alternatives (Dept of the Air Force, 1988). The Aircrew Training Research Division of the Armstrong Laboratory is actively engaged in research on the development of aircrew training simulators. Some simulators (and part-task trainers) have been placed with operational units for the purposes of aircrew research and development. A difficulty exists in that no widely accepted method of evaluating the benefit-cost impacts of these devices is in use. Because these simulators represent significant capital expenditures (Marcus, Patterson, Bennett, & Gershan, 1980; Orlansky & Chatelier, 1983), a method of evaluating their benefit-cost relationships is desired to help evaluate their usefulness from both a management and a research perspective.

Because many training needs exist at the operational (squadron and wing) level, it is desired that simulators be evaluated for this purpose rather than strictly as research or development tools. With today's technology, it is possible to design a simulation system that can represent almost all tasks a pilot might be called on to perform. This includes some tasks that, due to legal, ethical, safety, or security restrictions, cannot be easily practiced in the aircraft in peacetime even though performance of the tasks would be expected during times of war. In addition, advances in communication and data base technology makes it possible to link such simulators in networks enabling many pilots to engage in the same simulated exercises.

The above factors led to the objective of developing a method of applying benefit-cost analysis to simulators which are designed for implementation at the operational (squadron or wing) level. These simulators would be appropriate for multiship activity and training (McDonald, Broede, & Cutak, 1989). The purpose of the research reported in this report is to assist in accomplishment of this objective.

BACKGROUND

In 1990, W. C. Moor, working in conjunction with personnel at Armstrong Laboratory's Aircrew Training Research Division (AL/HRA), developed a preliminary model for the benefit-cost evaluation of multiship simulator alternatives (Moor, 1991a, 1991b; Moor & Andrews, 1992). This model, while it shows promise of meeting the objectives stated above, is in need of refinement and application testing. The model does demonstrate a complete method of benefit-cost analysis of multiship simulation alternatives and provides a means of computing the values for this analysis in a manner that is very straightforward (utilizing LOTUS 1-2-3 spreadsheets). Because much of the work presented in this report is an effort to improve the definitions and use of some of the variables required by this model, the names and definitions of these variables are shown in Table 1.

The original model developed a method for a complete benefit-cost analysis. This model included the capacity to evalute and compare multiple simulation environments as an explicit element. There were no differences in the computation method based on simulation environment. Therefore, this study focuses on refining the method of benefit determination for a single simulation environment assuming that this methhod can be generalized for multiple environments.

The current research focuses on the benefit component because it is elements of the benefits computation that require the most refinement. The general computational model for benefits determination is shown in Figure 1.

This focus on the benefits component is supported by two additional arguments. The first of these is that the original cost model was drawn from established Air Force policy and procedure (Dept of the Air Force, 1988; Knapp & Orlansky, 1983). Future efforts can refine the cost model following the procedures originally used in its development. It is not anticiapted that the overall method for benefits-cost computation and comparison would be significiatly altered by these refinements.

The second argument is that several operational and computational issues with respect to benefits determination had not been resolved. Chief among these is the use of the shadow cost of aircraft use as a basis for converting benefits into dollar terms. This issue is addressed in the next section of this report.

The overall thrust of the model building remains the same as for the original effort. The authors desire to make the computation model as clear as possible to the potential user and to build it in a form that facilitates use. In this case, all computational work is placed in LOTUS 1-2-3 spreadsheets that are annotated for data entry and use. The model is built in reference to a specifc, operational airacraft (chosen by the analyst) and is easily modified to allow comparisons for any air superiority jet fighter for which multiship simulators would be developed.

Table 1
Variable Identification and Definition
(Extracted from Moor, 1991a and Moor, 1991b)

Performance Area: An operational activity which would be required by a combat pilot and would be behaviorally complex enough that training emphasizing its acquisition and maintenance is appropriate. The Performance Area is identified as **PA(i)** where i refers to a specific performance area.

Continuation Use of the Simulator: The degree to which a simulator would be used to train in a performance area after initial skill training had been accomplished. The Continuation USE is identified as **CUSE(i)**.

Necessity of Use of the Simulator: The degree to which a simulator must be used to train in a performance area (usually because of extreme hazard/danger or legality of operation). The Necessity of USE is identified as **NUSE(i)**.

Emulation Capability of the Simulation Environment: The degree to which the simulation environment represents the actual environment experienced in the aircraft for the specific performance area. The Emulation capability of the SIMulation environment is identified as **ESIM(i)**.

Simulation Environment: The environment (inside the simulator) as experienced by the pilot. The SIMulation environment is identified as **SIM(j)**; where j refers to the specific simulation environment (different simulator).

Aircraft Training/Practice Sortie: A sortie where one, or more, of the performance areas would be practiced.

1. **Aircraft Sortie Duration** - the average time for such a sortie. The Aircraft sortie TIME is identified as **ATIME(i)**

2. **Performance Area Iterations** - the number of times the specific performance area could be practiced per sortie. The Aircraft REPetitions are identified as **AREP(i)**.

Simulation Training/Practice Sortie: A simulation sortie devoted to the practice of one, or more, specific performance areas.

1. **Simulation Sortie Duration** - the average time for such a sortie. This time period is intended to be held equal to the corresponding aircraft sortie duration to facilitate later computations. The Simulation sortie TIMEs are identified as **STIME(i)**.
2. **Simulation Performance Area Iterations** - the number of times a specific performance area could be practiced per simulation sortie. The Simulation REPetitions are identified as **SREP(i)**.

Table 1 (Concluded)

Degree of Simulation Compression: Ratio of the number of times a given Performance Area can be practiced in a simulator versus an aircraft. The Degree of Simulation Compression is identified as **DSC(i)** and is computed by SR(i)/AR(i)

Simulation Benefit Factor: This factor is used directly in computing the overall benefits imputed to each organizational alternative. The Simulation BENefit factor is identified as **SBEN(i)** and is computed by ESIM(i)*CUSE(i)*NUSE(i)*DSC(i).

Directly Measured Benefit Elements: These factors are based on the shadow costs for the use of aircraft and weaponry approximated by the marginal costs of this equipment.

1. **Marginal (incremental) Aircraft Cost** - Cost of flying the aircraft on a per sortie basis (or per hour, SHADAC$(i)), corrected for Performance Area if appropriate. The Marginal Aircraft Cost is identified as **MAC$(i)**.

2. **Weaponry Cost** - Cost of using ammunition, weaponry or other consumables expended per aircraft sortie for each Performance Area. This cost would include a factor for all damage (peacetime) due to the use of the weaponry. The WEAPonry cost is identified as **WEAP$(i)**.

Indirectly Measured Benefit Elements: These factors are based on potential losses of pilots and aircraft used in flying sorties. They are a measure of risk rather than training.

1. **Aircraft Loss Cost** - Cost of loss of the aircraft as a function of its use in flying sorties of the specific Performance Area. This is a probability-based measure computed by (Cost of an aircraft, TOTAC$)*(Probability of loss per sortie, PLOSSAC). The AIRcraft loss Cost is identified as **AIRC$(i)**.

2. **Pilot Death Cost** - Cost of losing a pilot due to training accident as a function of exposure to risk in specific Performance Areas. This is a probability-based measure computed by (cost of the pilot, TOTPIL$)*(Probability of loss per sortie, PLOSSPL). The PILot death Cost is identified as **PILC$(i)**.

Number of Simulation Sorties: The total number of simulation sorties that can be performed in a specified simulation environment for each Performance Area for each organizational alternative in a year (or other suitable time period). The NUMber of sorties is identified as **NUM(i)**.

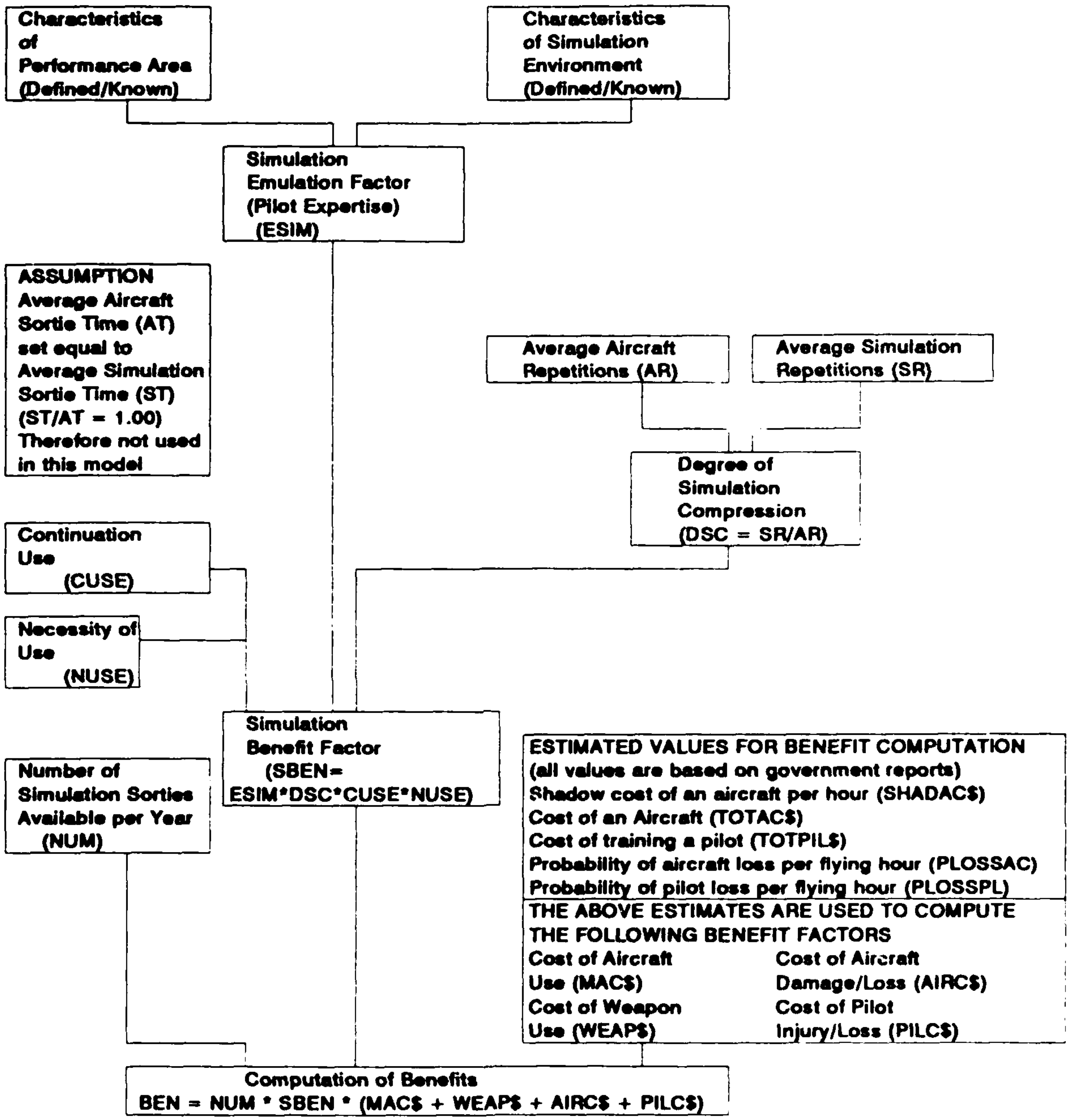

Figure 1
Flowchart of Benefits Computation
(Presented in terms of a single interface and a single performance area)
(Extracted from Moor 1991a)

BASIS FOR BENEFITS COMPUTATION

The model uses the shadow price of aircraft operation as the basis for benefits computation. It has been argued that this implies a direct trade of aircraft hours flown in exchange for hours spent in the simulator using the two variable economics utility trade-off curve (Orlansky and String, 1982). This trade-off was never intended, implicitly or explicitly.

While there are no perfect metrics for the creation of a dollar value for benefits imputed to a project (Maciariello, 1975; McDonald, et al., 1989; Smith, 1986), Schmid (1989) provides the best perspective of this issue. Arguably, in Schmid's discussion of the methods of computing benefit values, the method used here would appear to be the "Cost Saving Method" (Schmid, 1989, p. 66). However, the following argument shows that the use of the shadow price of the aircraft to form the basis of dollar estimation of benefits is more appropriately seen as the "Intermediate Good Method" (Schmid, 1989, p. 62) and this estimate is a minimum value for the comparison of two different simulators.

For purposes of this comparison, utility may be defined as the degree of "combat readiness." Figure 2 can be seen as presenting, at the squadron level, this utility in terms of the hours of training received, which reflects the syllabus describing the mixture of tasks which have been trained. The iso-utility curve shown describes the "trade-off" between simulator hours <u>of the simulators currently in use</u> and aircraft hours.

Aircraft hours flown is defined by the budgetary process which establishes the number of aircraft hours available in a given budget period. Then, within that budget, the number of hours flown may be reduced and replaced by <u>the current</u> simulator hours but cannot be increased. The replacement of aircraft hours with simulator hours would demand a large increase in total training hours (in order to maintain equivalent training) required of the pilots and would yield no better trained pilot than the current situation.

However, for a given budget level, it is reasonable to assume that the best trained pilots possible are being produced (The training syllabus is as good as possible in its mix of tasks trained and flown, <u>for that budget level</u>.). Therefore, there is no good reason to "trade-off" aircraft hours for simulator hours. At a different budget level, a different syllabus and/or mix of tasks to be flown would be used and would yield a different level of utility (training). This assumes no change in the simulators being used.

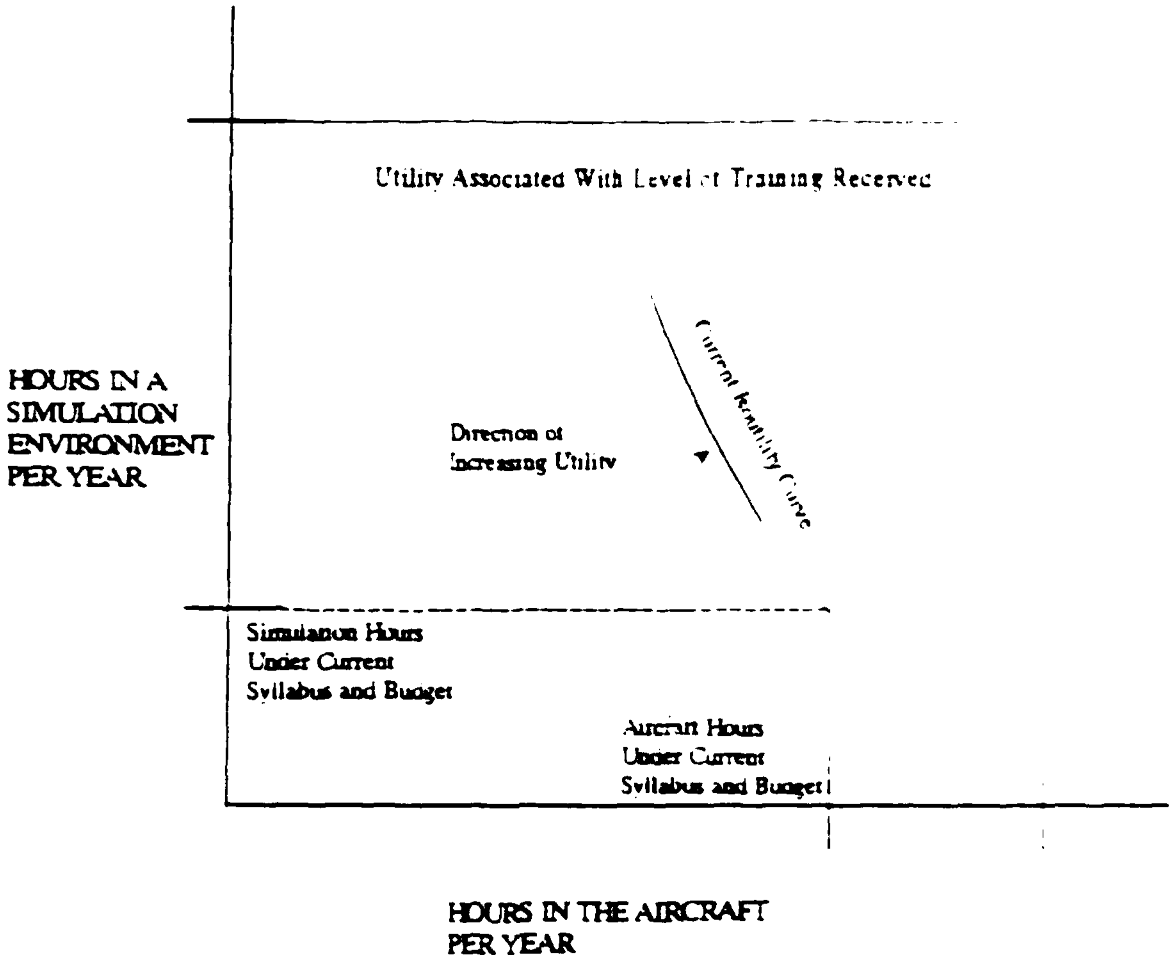

Figure 2
Isoutility Curve Illustrating Pilot Training
Under Current Training Conditions
(extracted from Moor, 1992)

If, with improved models of simulators and for a given level of aircraft flight hours, an apparent increase may be made in the hours of simulator time available (and corresponding changes to the training syllabus made) the isoutility curve is being changed (upward) yielding a better trained pilot. This "new" isoutility curve is one that is defined by an increased number of aircraft hours, even though no additional hours are authorized under the budget. This is illustrated by Figure 3.

Therefore, using the current budgeted marginal operating cost per aircraft hour as a starting point for benefit computation (the aircraft shadow price) is justifiable. Cost per aircraft operating hour is a "savings" (benefit) at the next

"higher" utility curve associated with the improved simulators (or simulator systems) that created the curve. Therefore, this benefit is a "fair" measure to use to compare simulator alternatives proposed to achieve this improvement. However due to the nature of using the marginal cost as a best estimate of the shadow price, if a different utility curve actually applied, the cost per aircraft operating hour would be different due to differences in operating economies. It appears reasonable, therefore, to start with the current operating cost and alter it incrementally to complete a parametric or sensitivity analysis.

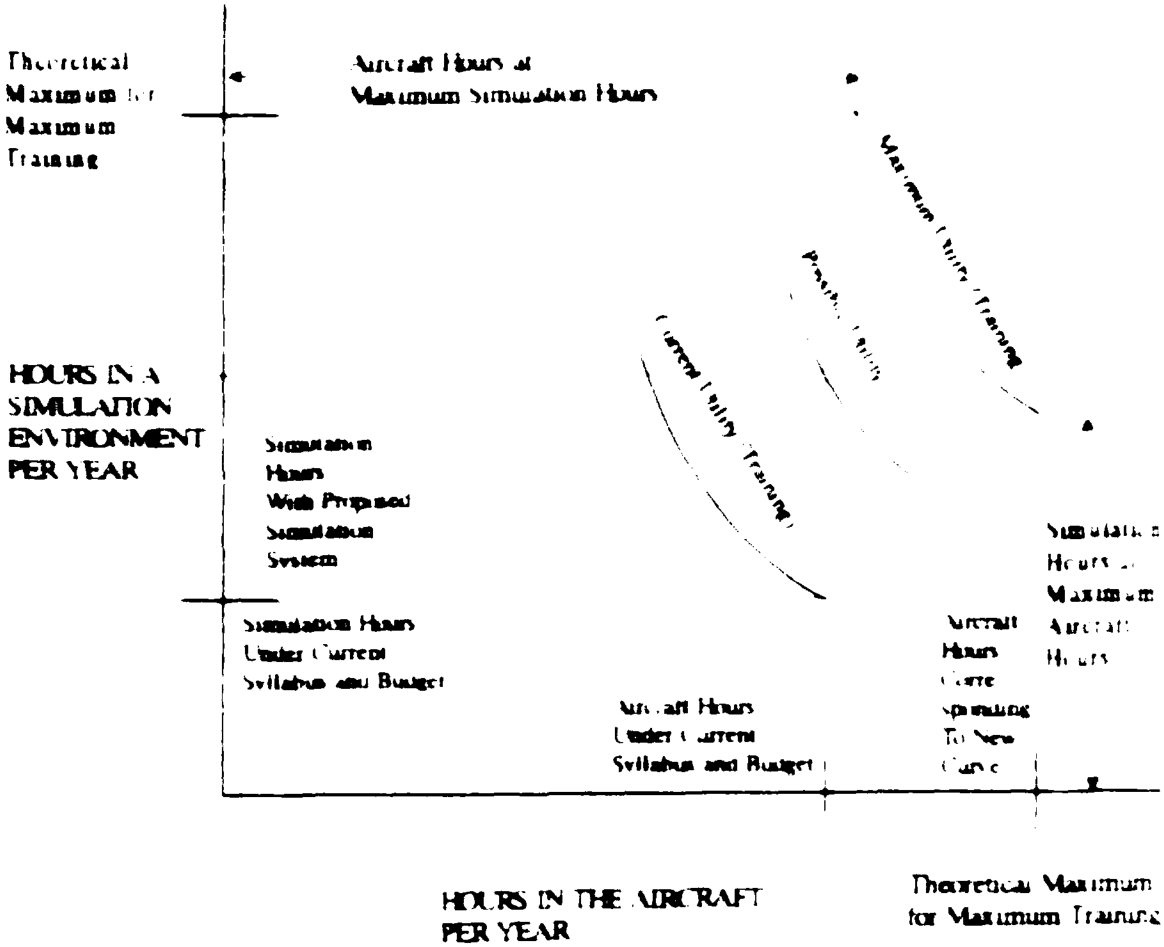

Figure 3
Isoutility Curve Illustrating Pilot Training
Under "New" Training Conditions
(extracted from Moor, 1992)

In addition, if the "new" simulators allowed the pilot to be further trained in skills which are currently not in the syllabus or which can be trained only rarely (for example, air combat skills currently practiced in major exercises available to the pilot once every year or two), then even further changes in the utility curve could be argued. The benefit-cost model, based on the shadow price of aircraft operating hours, provides a way to choose between competing proposed simulators for the provision of these enhanced skills.

Therefore, the benefits model presented in this paper uses the budgetarily defined number of aircraft operating hours (dollars/hour) as the basis for converting benefits into dollar terms. This provides a benefit comparison value for different proposed simulators that is an upper limit of the benefits possible for each simulator.

PERFORMANCE AREAS

Extensive research conducted using the F-15 simulators at McDonnell-Douglas Aircraft Company (McAir) (Houck & Thomas, 1989; Houck, Thomas, & Bell, 1991), has yielded an empirically derived set of "tasks" based on interviews with pilots that form the current basis for Performance Areas. A list of the performance areas and their definitions is provided in Table 2.

These performance areas are not mutually exclusive and therefore corrections must be made (allocations derived) when computing benefits. This is a relatively easy correction to make and will be more fully presented in the discussion of determining the number of simulation sorties performed. In addition, the performance areas do not form an exhaustive set of all pilot behaviors, however, an allowance is made to add performance areas to this list as necessary.

These performance areas have the advantage of being meaningful to pilots who can compare the simulated environment to the environment they experience in the aircraft. This yields meaning to the operational values for the simulator emulation (ESIM) variables. In addition, these areas include some that are rarely encountered and not part of the training manual.

The set of performance areas is probably too large (27 areas) to grasp for the purposes of making ESIM comparisons. It is proposed that when a simulator is to be evaluated, the developers of the simulator select those areas which are best presented by their system. The number created would probably be considerably smaller and would be most advantageous to that particular simulator. In this way, each simulator could be fairly compared on its own attributes. A questionnaire to facilitate this selection has been developed using the instructions and measurement scale shown in Table 3.

Table 2
F-15 Combat Tasks
A Spanning Set of Tasks for Multiship Operations
Representative, but not exhaustive
Used as the basis for the identification of Performance Areas
(Extracted from Houck, Thomas and Bell, 1991)

Tactics/Mission Planning and Briefing:
The beginning phases of the flight. Flight lead does specific mission planning (e.g., weather, target, tactics, threat, etc.), then briefs other flight members concerning the mission plan.

Mission Debriefing:
Postflight discussion of how closely the flight adhered to the briefed game plan, reasons for deviations, suggestions for improvement, etc. Should be used as a learning session.

Escort Tactics:
The specific tactics to be used for escorting other aircraft (e.g., bombers, electronic intelligence, radar, photo-reconnaissance), to protect them from any airborne threat. The aircraft being escorted should be briefed concerning the precise mission plan.

Visual Low Level:
Low level flight, usually flown approximately 500 feet above ground, using visual references for positioning and turn points.

Night Tactics:
Those tactics used for night missions. Usually relies more on radar use and precisely briefed tactics and maneuvers than do daylight missions.

Low Altitude Tactics:
Tactics specifically designed for use when your capability to "take it down" is limited or nonexistent.

Visual Lookout:
A briefed responsibility of each flight member as to where he is primarily to look for threats. For a single ship it is usually expressed as a percentage of time available, such as 70% visual, 30% radar.

Radar Lookout:
The reverse (percentage-wise) of visual lookout. More time is spent looking at the radar than outside.

Table 2 (Continued)

Tactical Formation:

The specific place each wingman should fly, with respect to flight lead, and his role designed to accomplish the specific mission, considering the threat, weather, weapons, etc.

Two-Ship Tactics:

Specific tactics designed to maximize the offensive and defensive capabilities of a two-ship flight.

Four-Ship Tactics:

Specific tactics designed to maximize the offensive and defensive capabilities of a four-ship flight.

Beyond-Visual-Range (BVR) Employment:

Tactics designed to operate in a BVR environment, where radar and radar missile capabilities must be considered.

All-Aspect Defense:

A defense based upon the premise that the enemy has the ability to fire weapons from anywhere in a 360° circle around the friendly aircraft, as opposed to a guns-only environment, where the enemy must fire from a close-in, stern area.

All-Weather Employment:

Employment tactics centered around radar capabilities, where visual weapons may not be able to be used.

Communications Jamming:

Tactics designed to minimize the effect of enemy communications jamming.

Tactical Electronic Warfare System (TEWS) Assessment:

Use of the onboard TEWS to detect potential threats, primarily via the radar warning receiver.

Electronic Countermeasure/Electronic Counter-Countermeasure (ECM/ECCM) Employment:

Use of ECM against a threat, or use of ECCM against enemy ECM.

Chaff/Flare Employment:

Use of chaff to defeat enemy radar missiles and flares to defeat enemy infrared missiles, based upon specific tactics.

Table 2 (Concluded)

Reaction to Surface-to-Air Missiles (SAMs):
Maneuvers designed to reduce the threat from or to defeat SAMs.

Reaction to Antiaircraft Artillery (AAA):
Maneuvers and tactics designed to reduce the threat from ground gunners.

Reaction to Air Interceptors (AIs):
Maneuvers and tactics designed to reduce the threat from enemy fighters.

Radar Employment/Sorting:
Tactics used for radar search and the sorting of enemy formations and individual formation members.

Visual Identification (VID):
Visually determining the identity of another aircraft.

Electronic Identification (EID):
Using electronic systems to determine the identity of another aircraft.

Tactical Intercept:
An intercept using specific single- or multiple-ship tactics, using either ground control radar or ownship radar.

Multibogey, Four or More:
Tactical employment against multiple enemy air threats.

Intraflight Communications:
The communications used between flight members, usually radio #2 and a specific discrete frequency.

Even in the case of two simulators which provided totally different training, a comparison utilizing the performance areas in which these simulators best trained would provide an indication of which simulator to select, if only one could be selected. The developers of the simulator provide the basis for comparison. The benefits computation would be made on the best use of the simulator, operating at its maximum efficiency. Therefore, selecting the one with the best benefit-cost ratio or maximum benefit minus costs should be easily defended.

Once the performance areas are specified by the developer of the simulator, training experts from the USAF would be asked to determine the relative desirability of each of these areas for the training. No performance area would be eliminated at this step, but a relative weighting would be obtained which would be used to determine the allocation of training time in the simulator. This allocation would be computed by multiplying the relative weighting (scaled to a summed

Table 3
Selection of Performance Areas
Instructions and Measurement Scale

Considering each of the following air combat tasks, please evaluate the total simulation environment (cockpit, visual, audio, etc.) in terms of its capability to represent the task from the pilots perspective in the aircraft.

Please use the following scale when evaluating each task.

Unacceptable:	The simulator is totally inappropriate for the task, it is possible that negative training could occur.
Marginal:	Significant deficiencies exist which requir correction before widespread use of the sy m.
Adequate:	System is usable, but could/should be greatly improved.
Acceptable:	Only minor deficiencies are noted.
Fully Acceptable:	No improvements are required.

Circle, or place a check mark on the evaluation scale for each task.

(All tasks are shown with definitions, space is provided to add tasks not on the list.)

value of 1.0) by the number of hours the simulator could be used if it were operational. No simulator sortie would ever be scheduled to train only one performance area, but the relative weightings are assumed to be constant for the purpose of computing the benefits values. A questionnaire has been developed to facilitate this weighting. The instructions and measuring scale for this questionnaire are shown in Table 4.

DETERMINATION OF NUSE AND CUSE VALUES

Once the performance areas are selected for a simulator which is to be evaluated and the relative training emphasis for each of these areas is established, it is necessary to determine the utilization characteristics for each area. Experts in training needs for the USAF would be asked to provide an evaluation of the timing of this training for mission-ready pilots. This evaluation would provide a measure of the continuity of training need (CUSE) and the necessity of using a simulator to meet this need (NUSE).

Table 4
Selection of Relative Weights of Performance Areas
Questionnaire Instructions and Measuring Scale

EVALUATION OF THE RELATIVE TIME SPENT TRAINING

Assuming the simulator were to be implemented for training at the squadron level and that the following set of tasks were the <u>only ones</u> to be trained using the simulator.

(List of performance areas, with definitions, derived for this simulator)

Show the relative amount of time that should be spent training Task A versus Task B.

Use the following scale:

1. Equal amount of time
2. Barely more time
3. Weakly more time
4. Moderately more time
5. Definitely more time
6. Strongly more time
7. Very strongly more time
8. Critically more time
9. Absolutely more time

If the relative time should be reversed between any two tasks indicate by showing reversing arrows, i. e.

```
 <-----------
TASK A      TASK B
 ----------->
```

TASK A   Relative Time   TASK B

_________   _________   _________

(Tasks shown on a paired comparison basis)

The values for CUSE and NUSE are both set to 1.00 by default, unless and until there is a clear reason to set them to some other value. The following decision rules have been developed to assign these values.

CUSE should be set at some value less than 1.00 when it is known that a particular simulator is <u>only</u> useful to train the initial phases of the performance area learning curve. CUSE would be set at the value of 0.50 if the simulator would not

be used to train the performance area at the mission-ready squadron level. Normally this would occur when the performance area was routinely practiced during any sortie.

NUSE should be set at a value of 2.00 if the performance area <u>cannot</u> be trained in the aircraft at the squadron level (due to legal, technological, or other restrictions) although the aircraft is fully capable of performing its portion of the task. The only way this performance area may be trained is through some form of special exercise or in a non-flying simulator. NUSE would be set to a value of 0.00 if the performance area cannot, and should not, be practiced in the simulator.

These evaluations are made with respect to the performance areas, not with respect to the specific simulator. The questionnaire asks the expert to rate each performance area according to the following categories. The values for CUSE and NUSE are shown according to these categories.

1. CONTINUOUS - Performance areas which are continually practiced (or ready to use on an intermittent basis) during the course of any sortie. No sortie is designed, necessarily, to practice these performance areas but they are performed (practiced) as needed, e.g., Intraflight Communications.

There would be no multiplier effect for these performance areas. A simulation sortie to practice them would be of the same duration and nature as an aircraft sortie to practice them. Generally, specific sorties would <u>not</u> be planned to practice these tasks.

CUSE would be assigned a value of 0.5, NUSE would be assigned a value of 1.0.

2. DISCRETE CLASS I - Performance areas which are performed a finite number (N) of times during the course of a sortie but, logically, would never be performed more than N times during any sortie of approximately equal duration, e.g., Night Tactics, Briefing/Debriefing.

There would be no multiplier effect (number of repetitions) involved in using the simulator to practice this performance area.

CUSE would be assigned a value of 1.0, NUSE would be assigned a value of 1.0.

3. DISCRETE CLASS II - Performance areas which are performed a finite number (N) of times during the course of a sortie planned for their practice. N repetitions are all that can be performed due to physical constraints on the environment, equipment, and/or pilot, e.g., Radar Employment/Sorting.

There would be a multiplier effect if the simulator, during the course of a sortie, could fully repeat the task N' times. N/N' is the repetition (REP) correction to apply to benefits determination. This must be determined by analysts familiar with the simulator and trainers (or subject matter experts (SMEs)) familiar with the aircraft.

CUSE would be assigned a value of 1.0, NUSE would be assigned a value of 1.0.

4. DISCRETE CLASS III - These are performance areas which can be performed during war or under extremely unusual and rarely occurring conditions (special exercises or locations for the sortie). Since this performance area is designed to be performed in the aircraft, a sortie may be specified and planned but it may not be actually practiced in the aircraft. Therefore, the sortie design is understood analytically.

Strictly speaking there is no multiplier effect accruing due to the use of the simulator (since N = 0), but for purposes of comparing different simulators, N may be arbitrarily set equal to 1. Then, if this performance area may be practiced one (or more) time per simulated sortie, the benefit factor would be "corrected" by a factor of 1/1, any further practice in the simulator yields a REP number enhancing benefit.

CUSE would be assigned a value of 1.0, NUSE would be assigned a value of 2.0.

These definitions and numeric assignments of values have been developed during the course of this report. They have not yet been validated as the most appropriate ones for the purpose of computing benefits values.

A questionnaire has been developed to ask the USAF experts how each performance area could be trained in the aircraft. This evaluation is used to provide the basis for numeric estimates for CUSE and NUSE and also a basis for the number of times a particular performance area could be repeated in a simulation sortie versus an aircraft sortie. The instructions for this questionnaire are shown in Table 5.

DETERMINATION OF ESIM VALUES

An empirical test of a questionnaire developed to acquire values for ESIM from pilots revealed the fact that all pilots questioned (N = 3) wanted to reserve the right to evaluate the capability of the simulator to represent the performance area in two dimensions. One of these was the dimension of initially acquiring the skills necessary to perform. The second dimension was the maintenance of the

Table 5
Determination of CUSE and NUSE Values
Questionnaire Instructions

TASK CHARACTERISTICS

The following are a set of descriptions concerning how tasks can be performed (or practiced) during aircraft sorties.

Please read these descriptions and apply them to the tasks which are presented on the next page.

1. CONTINUOUS - Tasks which are continually practiced (or ready to use on an intermittent basis) during the course of any sortie. No sortie is designed, necessarily, to practice these tasks but they are performed (practiced) as needed, e.g., Intraflight Communications.

2. DISCRETE CLASS I - Tasks which are performed a finite number (N) of times during the course of a sortie but, logically, would never be performed more than N times during any sortie of approximately equal duration, e.g., Night Tactics, Briefing/Debriefing.

3. DISCRETE CLASS II - Tasks which are performed a finite number (N) of times during the course of a sortie planned for their practice. N repetitions are all that can be performed due to physical constraints on the environment, equipment and/or pilot, e.g., Firing a particular missile (there are only N missiles per aircraft).

4. DISCRETE CLASS III - These are tasks which can be performed during war or under extremely unusual and rarely occurring conditions (special exercises or locations for the sortie). Since this task is designed to be performed in the aircraft, a sortie may be specified and planned but it may not be actually practiced in the aircraft. Therefore, the sortie design is understood analytically.

These instructions and definitions are followed by a listing of the performance areas and their definitions with space for the respondent to indicate his evaluation of the characteristic.

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skills necessary to perform. Therefore, two questionnaires were developed for this measure. The exact method of pooling this data has not yet been determined (other than an arithmetic average). Clearly this data would also be useful as a supplement to the evaluation of the CUSE values.

The questionnaire instructions and measuring scale for the acquisition of skills are shown in Table 6.

The instructions and measuring scale for the maintenance questionnaire are identical to the acquisition questionnaire except for necessary wording changes ("maintenance" replaces "acquisition").

Table 6
Acquisition of ESIM Values

EVALUATION OF SKILL ACQUISITION USING THE SIMULATOR

Consider each of the following Air Combat Tasks and using the following scale, rate the capability of the simulator to train the initial acquisition of the skills necessary to perform the task <u>at the squadron level.</u>

Scale of Measurement

Comparison of Learning to Perform a Task in the Simulator To Learning to Perform a Task in the Aircraft.

Measurement	Definition
0.00	Absolutely no training/learning potential in the simulator. The task must be trained/learned entirely in the F-15.
5.00	The task can be partially learned in the simulator but must be practiced in the F-15 to be fully learned.
10.00	Perfect training/learning environment in the simulator. The task never needs to be practiced in the F-15. Expectation is that, the first time the task is performed in the F-15, it will be performed correctly.

(This is followed by a list of the selected performance areas, their definitions and space for the respondent to indicate his/her numeric evaluation of that area.)

COMPUTING THE NUMBER OF TRAINING REPETITIONS

One of the major advantages that a simulator enjoys over the actual aircraft is that a given task may be practiced repeatedly without the need of refueling, rearming, disengaging and reengaging (unless these are the tasks to be practiced) which are required by the aircraft. A correction factor is built into the benefits computation model as a ratio of number of repetitions possible in the simulator

versus the number of repetitions possible in the aircraft with respect to a given performance area.

There would be no correction factor for any performance area which is classed as "Continuous" in its nature or "Discrete Category I." By the definitions of these terms, the performance areas so described would always be practiced the same "number of times" whether in the aircraft or the simulator.

Performance areas which are identified as "Discrete Category II" or "Discrete Category III" would be those which permit possible increased training repetitions in the simulator. Once the initial categorization of performance areas is accomplished, only those falling into the latter two categories would continue to be examined.

Experts in air training sortie design would be polled to determine how many times a particular performance area could be repeated during a "normal" training sortie intended for its practice. Similarly, experts in the nature of the simulator system would be polled as to how many times this performance area could be repeated in a simulation sortie under correct training conditions.

COMPUTING NUMBER OF SIMULATION SORTIES

The computation of benefits for a particular simulation system is directly dependent on the number of simulation sorties possible. Obviously, this depends on the number of simulators expected to be in use and the operating schedule for that use. It is proposed that, when simulators are to be compared, operating conditions as nearly equal as possible be used (hours of operation, number of simulation cockpits, etc.). The only differences allowed would be those technologically intrinsic to the simulator (required maintenance downtime, reliability, etc.).

The number of simulation sorties available may be easily computed based on the organizational configuration being examined through the use of a spreadsheet (identified as NUMCALC.WK1) developed for this project. This spreadsheet and the computational equations used in it are presented in Table 7.

The value computed by this spreadsheet (NUM) is used as a basis for comparison and also as a multiplier for the relative weightings determined for each performance area, therefore its importance cannot be overemphasized. Every effort must be made that completely valid figures be used when preparing the inputs for the computation of NUM.

Table 7
Data Spreadsheet (NUMCALC) to Compute Number of Simulation Sorties
(Shows range names and example computational equations)

FORM FOR THE COMPUTATION OF THE TOTAL NUMBER OF SIMULATION SORTIES THAT COULD BE FLOWN.
SORTIES ARE COMPUTED BY UNIT LEVEL AT WHICH THE SIMULATOR WOULD BE USED.

All numbers shown in this table are fictitious, for example only.

		UNIT LEVEL FOR COMPUTATIONS					
		SQUADRON		WING		REGIONAL	
		VARIABLE VALUE	RANGE NAME	VARIABLE VALUE	RANGE NAME	VARIABLE VALUE	RANGE NAME
INPUT VALUES ->	ORGANIZATIONAL CHARACTERISTICS:						
	NUMBER OF SIMULATORS PER UNIT	1	NSIMSQ	1	NSIMWG	1	NSIMRE
	NUMBER OF UNITS	1	NUMSQ	1	NUMWG	1	NUMRE
	OPERATING CHARACTERISTICS PER UNIT:						
	NUMBER OF HOURS OPERATED PER DAY	8	NHRDYSQ	10	NHRDYWG	12	NHRDYRE
	NUMBER OF DAYS OPERATED PER WEEK	5	NDYWKSQ	6	NDYWKWG	6	NDYWKRE
	NUMBER OF WEEKS OPERATED PER YEAR	52	NWKYRSQ	50	NWKYRWG	52	NWKYRRE
	SORTIE DURATION	1.5	SRTMSQ	1.2	SRTMWG	1.5	SRTMRE
	AVERAGE BRIEFING TIME PER SORTIE (HOURS)	1	BRFTMSQ	1	BRFTMWG	1.2	BRFTMRE
	AVERAGE DEBRIEFING TIME PER SORTIE (HOURS)	1.5	DBRFTMSQ	1.1	DBRFTMWG	1.3	DBRFTMRE
	UTILIZATION RATE (AVAILABILITY PER DAY) (stated as a decimal between 0.00 and 1.00)	80.00%	UTILSQ	90.00%	UTILWG	96.00%	UTILRE
OUTPUT VALUES ->	NUMBER OF SORTIES PER DAY PER SIMULATOR	2.933	NSORTSQ	5.925	NSORTWG	6.08	NSORTRE
	INTEGER NUMBER OF SORTIES PER DAY PER SIMULATOR	2	NNSORTSQ	5	NNSORTWG	6	NNSORTRE
	TOTAL NUMBER OF SORTIES PER YEAR FOR THIS UNIT LEVEL (this is used as the basis for TOTNUM(j) in the benefits computation)	520	TOTNUMSQ	1500	TOTNUMWG	1872	TOTNUMRE

Representative calculations (using RANGE NAMES) are shown below

RANGE NAME for output figure	Computational equation
NSORTSQ	(($NHRDYSQ-$BRFTMSQ-$DBRFTMSQ)*$UTILSQ)/$SRTMSQ
NNSORTSQ	@INT($NSORTSQ)
TOTNUMSQ	+$NNSORTSQ*$NDYWKSQ*$NWKYRSQ*$NSIMSQ*$NUMSQ

ESTIMATION OF BENEFIT CONVERSION FACTORS

The establishment of benefits accruing to any simulation alternative is based on a comparison to a specific aircraft for which aircrew training is necessary. Most of the modeling presented to this point (with the exception of several specific references to sortie training) has been as generic as possible. This would facilitate the evaluation of simulators proposed for any air superiority aircraft training. The final conversion of modeled variables to benefit values, however, does require the specification of the aircraft. The original test of this model referenced the F-15 and this reference is maintained at this point.

1. SHADOW COST OF THE AIRCRAFT - The original argument for the determination of the shadow cost of the aircraft was that the appropriate value to start with was the marginal operating cost of flying. This argument is expanded in an earlier section of this report utilizing the concept of expanded training capability. Based on 1992/1993 USAF budget figures the cost is estimated (Dept. of the Air Force, 1988a, 1991).

SHADOW COST OF THE AIRCRAFT = $5,000 per flying hour

2. WEAPONS USE BY PERFORMANCE AREA - The model includes the capacity to treat as a benefit the cost savings accruing to weapon deployment in the simulator that does not represent the actual consumption of the weapon. This value depends on the performance area being trained; many performance areas require no weapon use, others require a variety of different very expensive weapons to be used. This factor is in the model and is available for further refinement but at present it is not used.

WEAPONS COST (PERFORMANCE AREA) = $0

3. PILOT COST - The possibility of a pilot flying a sortie incurring an accident which leads to death or injury is very real. Training in a non-flying simulator would reduce this possibility to negligible terms. Therefore, a benefit is computed corresponding to the cost of training the pilot multiplied by the probability of death and/or injury per flying hour. Currently, this benefit factor uses only the cost of training a pilot (General Accounting Office, 1987) corrected by a USAF inflation correction factor (Directorate of Engineering and Services, 1988) multiplied by a rough estimate of pilot death while flying (Dept. of the Air Force, 1988). The cost of injury could be implemented but is not part of the model.

PILOT COST = ($7,504,281 x 1.18028) x (0.0000205)
= $182 per flying hour

4. AIRCRAFT COST - The cost accruing due to loss of the aircraft is treated in a similar manner and for a similar reason as the cost of the pilot. The benefit factor allows for the use of cost of damage but this value is not yet implemented. Currently, this benefit factor uses only the cost of replacing the aircraft (drawn from USAF budget figures (Dept. of the Air Force, 1988a, 1988b) multiplied by a rough estimate of the probability of the total loss of the aircraft (Dept. of the Air Force, 1992). Since the values are drawn for the F-15 (not F-15E), this must be seen as an arbitrary estimate. The aircraft is no longer being manufactured and would not be identically replaced if lost.

AIRCRAFT COST = ($40,000,000) x (0.0000308)
= $1232 per flying hour

BENEFITS COMPUTATION MODEL

The total benefits computation model that was originally developed has been modified to include all the factors that are described in this report. The general benefits computation equation is shown in Figure 1. In addition, editing comments to assist in data entry and range names identifying each cell have been placed on the spreadsheets which are the operational representation of the model. The benefits computation spreadsheet (NEWBEN.WK1) is described in this section and is illustrated in Table 8. The spreadsheet (NUMCALC.WK1) to determine the number of sorties (NUM) operationally available for any specific simulation configuration has been described in a previous section. The files, named as indicated and in LOTUS 1-2-3 format, are available to anyone who wishes to examine them.

The benefits spreadsheet allows for up to eight different performance areas to be named and entered. More performance areas may be used but the spreadsheet must be modified to accommodate this increase by adding rows to the spreadsheet and duplicating the computational equations as necessary.

The spreadsheet model consists of a number of input and output vectors and matrices which are clearly labeled as to purpose. It includes the capability of simultaneously evaluating up to four distinctly different (or four variants) simulator environments. These are labeled with a column in each matrix corresponding to a different environment.

TEST OF THE BENEFITS COMPUTATION PROCEDURE

A preliminary test of the procedure and benefits computation model was conducted as part of this report. The simulator used as a focus was the Air Intercept Trainer (AIT) which is currently in use with several Air National Guard F-16 squadrons and which was developed by Armstrong Laboratory (Figure 4). (It

Table 8

Spreadsheet (NEWBEN.WK!) Showing Method for Computing Benefits

A representative computational equation is presented for output

Range names are assigned to each cell as shown

MASTER TABLE FOR IDENTIFYING RANGE NAMES AND VALUES
BENEFIT COMPUTATION FOR MULTISHIP PROJECT
INPUT VECTORS AND MATRICES ARE IDENTIFIED AS "INPUT"
COMPUTATION RESULT VECTORS AND MATRICES ARE
IDENTIFIED AS "OUTPUT".

CHECK VALUE = 1E+08
IF THE ABOVE CELL CONTAINS ANYTHING OTHER THAN "BLANK" OR 0.0
ONE OR MORE OF THE INPUT CELLS HAS A VALUE IN IT.
THE USER SHOULD VERIFY ALL INPUT VALUES

THIS REPRESENTS MASTER DATA
FOR ALL ORGANIZATION ALTERNATIVES

	"INPUT"	"INPUT"		"INPUT"		"INPUT" Matrix of Values for Emulation Measures ESIM(i,j) Simulation Interfaces (j)							
Names of Performance Areas	Performance Areas (i)	Continuation Use CUSE(i)	RANGE NAME	Necessity of Use NUSE(i)	RANGE NAME	Inter-face # 1	RANGE NAME	Inter-face # 2	RANGE NAME	Inter-face # 3	RANGE NAME	Inter-face # 4	RANGE NAME
NAME 1	1	1.00	CUSE1	1.00	NUSE1	0.0150	ESIM11	0.0300	ESIM12	0.0700	ESIM13	0.1000	ESIM14
NAME 2	2	1.00	CUSE2	1.00	NUSE2	0.0150	ESIM21	0.0300	ESIM22	0.0700	ESIM23	0.1000	ESIM24
NAME 3	3	1.00	CUSE3	1.00	NUSE3	0.0150	ESIM31	0.0300	ESIM32	0.0700	ESIM33	0.1000	ESIM34
NAME 4	4	1.00	CUSE4	1.00	NUSE4	0.0150	ESIM41	0.0300	ESIM42	0.0700	ESIM43	0.1000	ESIM44
NAME 5	5	1.00	CUSE5	1.00	NUSE5	0.0150	ESIM51	0.0300	ESIM52	0.0700	ESIM53	0.1000	ESIM54
NAME 6	6	1.00	CUSE6	1.00	NUSE6	0.0150	ESIM61	0.0300	ESIM62	0.0700	ESIM63	0.1000	ESIM64
NAME 7	7	1.00	CUSE7	1.00	NUSE7	0.0150	ESIM71	0.0300	ESIM72	0.0700	ESIM73	0.1000	ESIM74
NAME 8	8	1.00	CUSE8	1.00	NUSE8	0.0150	ESIM81	0.0300	ESIM82	0.0700	ESIM83	0.1000	ESIM84
Enter the names of the performance areas (tasks) that are to serve as the basis for this evaluation.		Enter the value of 1.00 if the simulator can be used to maintain skills in this area for the mission ready pilot. Enter 0.50 if the simulator can only be used to train the initial acquisition of skills.		Enter the value of 2.00 if the simulator can be used to train a skill that cannot be trained in the aircraft. Enter 1.00 if simulator can be used in parallel with the aircraft. Enter 0.0 if the simulator should not be used.		These values should come from interview or questionnaire evaluations performed by expert pilots. They should be scaled from 0.0000 to 1.0000							

Table 8 (Continued)

"INPUT" Aircraft Measures		"INPUT"		"INPUT"		Simulation Measures				"INPUT" Simulation Repetitions SREP(I,J) Note: STIME(I) is held = ATIME(I)			
Aircraft Sortie Time		Aircraft Repetitions		Simulation Sortie Time									
ATIME(I)	RANGE NAME	AREP(I)	RANGE NAME	STIME(I)	RANGE NAME	Inter-face # 1	RANGE NAME	Inter-face # 2	RANGE NAME	Inter-face # 3	RANGE NAME	Inter-face # 4	RANGE NAME
1.40	ATIME1	6	AREP1	1.40	STIME1	10	SREP11	10	SREP12	10	SREP13	10	SREP14
1.30	ATIME2	3	AREP2	1.30	STIME2	8	SREP21	8	SREP22	8	SREP23	8	SREP24
1.30	ATIME3	3	AREP3	1.30	STIME3	8	SREP31	8	SREP32	8	SREP33	8	SREP34
1.30	ATIME4	3	AREP4	1.30	STIME4	8	SREP41	8	SREP42	8	SREP43	8	SREP44
1.40	ATIME5	6	AREP5	1.40	STIME5	10	SREP51	10	SREP52	10	SREP53	10	SREP54
1.30	ATIME6	3	AREP6	1.30	STIME6	8	SREP61	8	SREP62	8	SREP63	8	SREP64
1.30	ATIME7	3	AREP7	1.30	STIME7	8	SREP71	8	SREP72	8	SREP73	8	SREP74
1.40	ATIME8	4	AREP8	1.40	STIME8	10	SREP81	10	SREP82	10	SREP83	10	SREP84
This should be the average length of the sortie during which this task would be trained in the aircraft.		This should be the average number of times this task would be repeated in an aircraft sortie.		This should be the average length of a simulator sortie designed to practice this task.		Each entry should be the average number of times this task may be fully repeated in the particular simulator interface being evaluated.							

Table 8 (Continued)

"OUTPUT"
Simulation Benefit Factors

Computation Equation SBEN(i,j) =
ESIM(i,j)*(SREP(i,j)/AREP(i))*(STIME(i)/ATIME(i))*(CUSE(i)*NUSE(i))

Interface # 1	RANGE NAME	Interface # 2	RANGE NAME	Interface # 3	RANGE NAME	Interface # 4	RANGE NAME
0.02500	SBEN11	0.05000	SBEN12	0.11667	SBEN13	0.16667	SBEN14
0.04000	SBEN21	0.08000	SBEN22	0.18667	SBEN23	0.26667	SBEN24
0.04000	SBEN31	0.08000	SBEN32	0.18667	SBEN33	0.26667	SBEN34
0.04000	SBEN41	0.08000	SBEN42	0.18667	SBEN43	0.26667	SBEN44
0.02500	SBEN51	0.05000	SBEN52	0.11667	SBEN53	0.16667	SBEN54
0.04000	SBEN61	0.08000	SBEN62	0.18667	SBEN63	0.26667	SBEN64
0.04000	SBEN71	0.08000	SBEN72	0.18667	SBEN73	0.26667	SBEN74
0.03750	SBEN81	0.07500	SBEN82	0.17500	SBEN83	0.25000	SBEN84

This contains intermediate values computed by the spreadsheet.
DO NOT make entries.

"OUTPUT"
NUM(i,j) is a function of the total number of simulation sorties designated by TOTNUM(j) (TOTNUM may be arbitrary or come from the NUMCALC spreadsheet) and the proportionate fractions (PROP(i,j)) generated by expert opinion.
Note that NUM(i,j) is also a function of scheduling AND absolute throughputs achievable by the organizational alternative being evaluated.
Computation Equation NUM(i,j) = TOTNUM(j)*PROP(i,j)

NUM(i,j) per year

Interface # 1	RANGE NAME	Interface # 2	RANGE NAME	Interface # 3	RANGE NAME	Interface # 4	RANGE NAME
5760	NUM11	7200	NUM12	1920	NUM13	3120	NUM14
11520	NUM21	7200	NUM22	1920	NUM23	3120	NUM24
17280	NUM31	7200	NUM32	1920	NUM33	3120	NUM34
2880	NUM41	7200	NUM42	1920	NUM43	3120	NUM44
2880	NUM51	7200	NUM52	2880	NUM53	2080	NUM54
2880	NUM61	7200	NUM62	2880	NUM63	2080	NUM64
5760	NUM71	7200	NUM72	2880	NUM73	2080	NUM74
8640	NUM81	7200	NUM82	2880	NUM83	2080	NUM84

TOTNUM(j) ----> 57600 TOTNUM1 57600 TOTNUM2 19200 TOTNUM3 20800 TOTNUM4
^
|
"INPUT"

"INPUT"

Proportion of the total sorties available in the organizational alternative which should be devoted to Performance Area i. Note: This may also refer to a proportion of one sortie or some combination of sorties. It is intended as an overall allocation of effort based on expert opinion.

PROP(i,j) is proportion of sorties

PERFORMANCE AREA	Interface # 1	RANGE NAME	Interface # 2	RANGE NAME	Interface # 3	RANGE NAME	Interface # 4	RANGE NAME
1	0.1000	PROP11	0.1250	PROP12	0.1000	PROP13	0.1500	PROP14
2	0.2000	PROP21	0.1250	PROP22	0.1000	PROP23	0.1500	PROP24
3	0.3000	PROP31	0.1250	PROP32	0.1000	PROP33	0.1500	PROP34
4	0.0500	PROP41	0.1250	PROP42	0.1000	PROP43	0.1500	PROP44
5	0.0500	PROP51	0.1250	PROP52	0.1500	PROP53	0.1000	PROP54
6	0.0500	PROP61	0.1250	PROP62	0.1500	PROP63	0.1000	PROP64
7	0.1000	PROP71	0.1250	PROP72	0.1500	PROP73	0.1000	PROP74
8	0.1500	PROP81	0.1250	PROP82	0.1500	PROP83	0.1000	PROP84
Double Check That Sum of Proportions Equals 1.00 -->	1.0000		1.0000		1.0000		1.0000	

Table 8 (Continued)

OUTPUT

Aircraft
Use
Cost per sortie

Computation Equation
MAC$(i) =
SHADAC$(i)*ATIME(i)

MAC$(i)	RANGE NAME
$6,300.00	MAC$1
$5,850.00	MAC$2
$5,850.00	MAC$3
$5,850.00	MAC$4
$6,300.00	MAC$5
$5,850.00	MAC$6
$5,850.00	MAC$7
$6,300.00	MAC$8

INPUT

BENEFIT ELEMENTS

Shadow cost of an aircraft per hour (SHADAC$):	$4,500.00
Cost of an aircraft (TOTAC$):	$38,000,000
Cost of the pilot (TOTPIL$):	$8,400,000
Probability of aircraft loss per flying hour (PLOSSAC):	0.000005
Probability of pilot loss per flying hour (PLOSSPL):	0.00001

These elements may be found in annual budget figures from the USAF and other published sources.

Benefit Conversion Factors

INPUT

Weapons
Use

No Computation
Equation

WEAP$(i)	RANGE NAME
$2,000.00	WEAP$1
$2,000.00	WEAP$2
$2,000.00	WEAP$3
$2,000.00	WEAP$4
$2,000.00	WEAP$5
$2,000.00	WEAP$6
$2,000.00	WEAP$7
$2,000.00	WEAP$8

Cost of Weapons Use on a per task basis when trained in the aircraft. Determined by task description and analysis.

OUTPUT

Loss of
Aircraft
Computation
Equation
AIRC$(i) =
TOTAC$*PLOSSAC
*ATIME(i)

AIRC$(i)	RANGE NAME
$266.00	AIRC$1
$247.00	AIRC$2
$247.00	AIRC$3
$247.00	AIRC$4
$266.00	AIRC$5
$247.00	AIRC$6
$247.00	AIRC$7
$266.00	AIRC$8

OUTPUT

Loss of
Pilot
Computation
Equation
PILC(i) =
TOTPIL$*PLOSSPL
*ATIME(i)

PILC$(i)	RANGE NAME
$117.60	PILC$1
$109.20	PILC$2
$109.20	PILC$3
$109.20	PILC$4
$117.60	PILC$5
$109.20	PILC$6
$109.20	PILC$7
$117.60	PILC$8

Table 8 (Concluded)

OVERALL BENEFITS IMPUTED TO THIS ORGANIZATIONAL ALTERNATIVE
This matrix shows values for all component parts of each of the simulation interfaces.
It does NOT show the benefit for any particular organizational alternative.

Each benefit element = NUM(i,j)*SBEN(i,j)*{MAC$(i)+WEAP$(i)+AIRC$(i)+PILC$(i)}

This is the summation of all elements of the benefit matrix
$121,012,603.31

Since these values represent the final output of the computation,
no range names are assigned to these locations

	1	2	3	4
	$1,250,438.40	$3,126,096.00	$1,945,126.40	$4,515,472.00
	$3,781,416.96	$4,726,771.20	$2,941,102.08	$6,827,558.40
	$5,672,125.44	$4,726,771.20	$2,941,102.08	$6,827,558.40
	$945,354.24	$4,726,771.20	$2,941,102.08	$6,827,558.40
	$625,219.20	$3,126,096.00	$2,917,689.60	$3,010,314.67
	$945,354.24	$4,726,771.20	$4,411,653.12	$4,551,705.60
	$1,890,708.48	$4,726,771.20	$4,411,653.12	$4,551,705.60
	$2,813,486.40	$4,689,144.00	$4,376,534.40	$4,515,472.00
TOTAL ESTIMATED BENEFITS	$17,924,103.36	$34,575,192.00	$26,885,962.88	$41,627,345.07

should be noted that the AIT is regarded as more of a "multi-task" part-task trainer, than as a full multi-task simulator.) Several of the AL/HRA personnel, who had helped develop and implement the AIT, assisted as "experts" for questionnaire-based input and three pilots, mission ready and experienced with the AIT (although not necessarily F-16 qualified), served as "experts" for pilot input. The aircraft serving as the basis for benefits computation was the F-16. The procedural steps are described below.

1. The initial step was to administer a questionnaire to two of the AL/HRA experts asking them to select the performance areas, from the list of 27, that the AIT was designed to perform and their impressions of the quality of this performance. Those performance areas which received a vote of "Acceptable" or better from both were selected as the evaluation performance areas. These yielded a set of eight performance areas as a basis for the remaining benefits estimation. These eight areas are named and defined in Table 9.

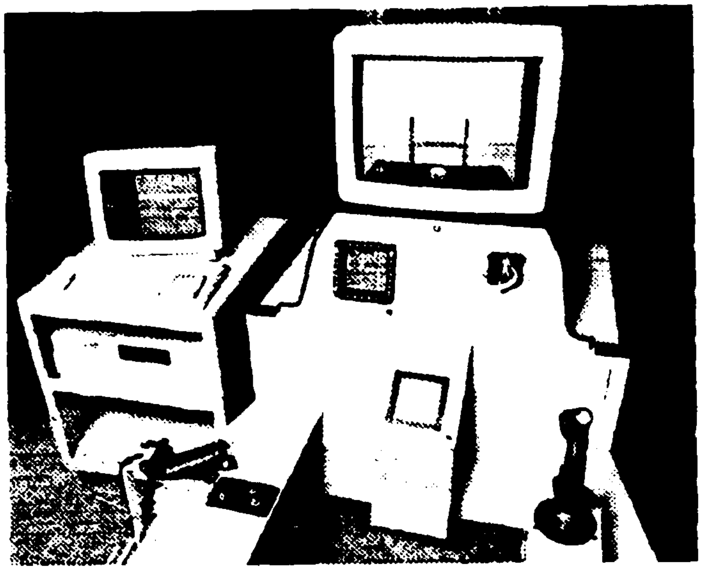

Figure 4
The Air Intercept Trainer (AIT)
(Top View)

2. The same two experts then were asked to perform the paired comparison of these eight areas to determine the relative time that should be devoted to each of them in allocating simulation use. This comparison was facilitated through the use of the CRITERIUM (Criterium Reference Guide, 1989) software package which uses a comparison scale drawn from the Analytic Hierarchy Process (Saaty, 1980) to automatically determine relative weightings (proportions) and consistency evaluations. These proportions were input to the benefits matrix prior to determining the number of simulation sorties that could be flown by performance area. These proportions are shown on the overall benefits estimated model presented in Table 10.

3. The decision was made to evaluate one pair of AIT simulators implemented into one Air National Guard squadron. The AL/HRA experts, who were familiar with the operating character of this squadron, provided input for the computation of the total number (NUM) of simulation sorties available. The results of this computation are shown in Table 11.

4. A different AL/HRA manager, who was knowledgeable about the AIT and who had helped develop the initial list of performance areas, completed the questionnaire providing preliminary values for CUSE and NUSE. These values are shown on Table 13. In this table, the CUSE and NUSE determinations are highlighted by the "C" and "DC2" (the only two categories for these performance areas) attached to the names of each performance area.

Table 9
Performance Areas Selected for AIT Evaluation

Radar Lookout: A briefed responsibility of each flight member as to where he is primarily to look for threats. For a single ship it is usually expressed as a percentage of time available, more time is spent looking at the radar than outside.

Tactical Formation: The specific place each wingman should fly, with respect to flight lead, and his role designed to accomplish the specific mission, considering the threat, weather, weapons, etc.

Two-Ship Tactics: Specific tactics designed to maximize the offensive and defensive capabilities of a two-ship flight.

Four-Ship Tactics: Specific tactics designed to maximize the offensive and defensive capabilities of a four-ship flight.

Beyond-Visual-Range (BVR) Tactics: Tactics designed to operate in a BVR environment, where radar and radar missile capabilities must be considered.

Radar Search/Sorting: Use of radar for search and sorting of enemy formations.

Tactical Intercept: An intercept using specific single or multiple ship tactics, using either ground control radar or ownship radar.

Multibogey, Two or More: Tactical employment against multiple enemy air threats.

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5. The three pilots then evaluated each of the eight areas with respect to the capability of the AIT to provide emulation capability with respect to the aircraft. (It was at this point that the distinction between "acquisition of ability" and "maintenance of ability" was requested and accepted for current purposes.) The averages for each performance area and each use was maintained yielding a total of two simulation environments to be compared. The data for ESIM evaluation is presented in Table 12, average values are used for benefits computation.

6. All experts were polled to determine the expected number of repetitions of each performance area. This same poll yielded average duration of aircraft sortie and simulation sortie. This information was also used to complete the numerical evaluation of the CUSE and NUSE variables.

7. All benefits computation values presented earlier (in the context of the F-15) were corrected to be representative of the F-16.

The final results of this preliminary test are shown in Table 13. Due to the preliminary nature of the data collection instruments this should not be considered

Table 10
Relative Time To Be Spent Training Each Performance Area
AIT Example

	RELATIVE PROPORTION OF TIME SPENT EVALUATORS RATINGS		
NAME OF PERFORMANCE AREA	1	2	AVERAGE
Beyond-Visual-Range Employment	24.87%	15.27%	20.07%
Radar Lookout	14.08%	38.64%	26.36%
Tactical Formation	3.02%	7.62%	5.32%
Two-Ship Tactics	8.22%	3.90%	6.06%
Four-Ship Tactics	2.99%	2.27%	2.63%
Radar Employment/Sorting	25.15%	20.55%	22.85%
Tactical Intercept	18.60%	9.66%	14.13%
Multibogey, Four or More	3.07%	2.10%	2.59%

a true benefits evaluation of the AIT. It would be extremely misleading to interpret these numerical values as anything other than tentative at best.

CONCLUSIONS AND RECOMMENDATIONS

This report improved and refined the benefits model developed in previous work. It created the operational procedures necessary to acquire all data required for estimating benefits. In addition, the report completed an operational test of these procedures demonstrating their feasibility.

The report did not address additional refinement of the original cost model or the model used to present benefit cost summary information. These models are available as originally developed in 1990.

Obvious areas requiring future research are listed in the report. These include improvements and refinements in the methods of: a) acquiring and using the CUSE and NUSE values; b) validating the ESIM values; c) validating the use of the master list of performance areas; d) justifying the proportionality values for the number of simulation sorties per performance area; and, e) determining the general usability of the operational procedures. Additional areas for further development are those cited above.

Table 11
Total Number of Simulation Sorties – AIT Test Case

FORM FOR THE COMPUTATION OF THE TOTAL NUMBER OF SIMULATION SORTIES THAT COULD BE FLOWN.
SORTIES ARE COMPUTED BY UNIT LEVEL AT WHICH THE SIMULATOR WOULD BE USED.

THESE CALCULATIONS ARE FOR A SINGLE PAIR OF AIT SIMULATORS AT THE SQUADRON LEVEL.

		UNIT LEVEL FOR COMPUTATIONS					
		SQUADRON VARIABLE VALUE	RANGE NAME	WING VARIABLE VALUE	RANGE NAME	REGIONAL VARIABLE VALUE	RANGE NAME
INPUT VALUES	ORGANIZATIONAL CHARACTERISTICS:						
	NUMBER OF SIMULATORS PER UNIT	2	NSIMSQ	0	NSIMWG	0	NSIMRE
	NUMBER OF UNITS	1	NUMSQ	0	NUMWG	0	NUMRE
	OPERATING CHARACTERISTICS PER UNIT:						
	NUMBER OF HOURS OPERATED PER DAY	12	NHRDYSQ	0	NHRDYWG	0	NHRDYRE
	NUMBER OF DAYS OPERATED PER WEEK	6	NDYWKSQ	0	NDYWKWG	0	NDYWKRE
	NUMBER OF WEEKS OPERATED PER YEAR	44	NWKYRSQ	0	NWKYRWG	0	NWKYRRE
	SORTIE DURATION	1.5	SRTMSQ	0	SRTMWG	0	SRTMRE
	AVERAGE BRIEFING TIME PER SORTIE (HOURS)	0.2	BRFTMSQ	0	BRFTMWG	0	BRFTMRE
	AVERAGE DEBRIEFING TIME PER SORTIE (HOURS)	0.3	DBRFTMSQ	0	DBRFTMWG	0	DBRFTMRE
	UTILIZATION RATE (AVAILABILITY PER DAY) (stated as a decimal between 0.00 and 1.00)	95.00%	UTILSQ	0.00%	UTILWG	0.00%	UTILRE
OUTPUT VALUES	NUMBER OF SORTIES PER DAY PER SIMULATOR	7.2833	NSORTSQ	ERR	NSORTWG	ERR	NSORTRE
	INTEGER NUMBER OF SORTIES PER DAY PER SIMULATOR	7	NNSORTSQ	ERR	NNSORTWG	ERR	NNSORTRE
	TOTAL NUMBER OF SORTIES PER YEAR FOR THIS UNIT LEVEL (this is used as TOTNUM(j) in the benefits computation)	3696	TOTNUMSQ	ERR	TOTNUMWG	ERR	TOTNUMRE

NOT USED FOR THIS EXAMPLE

Table 12
ESIM Values for the AIT Example Case

	PILOTS AND EVALUATIONS							
	PILOT #1		PILOT #2		PILOT #3		Average for Initial Acquisition	Average for Maintenance of Skill
TASKS EVALUATED	Initial Acquisition of Skill	Maintenance of Skill	Initial Acquisition of Skill	Maintenance of Skill	Initial Acquisition of Skill	Maintenance of Skill		
1. Beyond-Visual-Range Employment	0.80000000	0.80000000	0.05000000	0.04000000	0.80000000	0.80000000	0.55000000	0.54666667
2. Radar Lookout	0.80000000	0.80000000	0.35000000	0.25000000	0.40000000	0.40000000	0.51666667	0.48333333
3. Tactical Formation	0.20000000	0.30000000	0.06000000	0.04000000	0.30000000	0.20000000	0.18666667	0.18000000
4. Two-Ship Tactics	0.60000000	0.60000000	0.20000000	0.15000000	0.30000000	0.10000000	0.36666667	0.28333333
5. Four-Ship Tactics	0.40000000	0.00000000	0.15000000	0.13000000	0.20000000	0.10000000	0.25000000	0.07666667
6. Radar Employment/Sorting	0.90000000	0.70000000	0.35000000	0.25000000	1.00000000	1.00000000	0.75000000	0.65000000
7. Tactical Intercept	1.00000000	0.90000000	0.40000000	0.30000000	0.90000000	0.80000000	0.76666667	0.66666667
8. Multibogey, Four or More	0.90000000	0.90000000	0.17500000	0.14000000	0.10000000	0.10000000	0.39166667	0.38000000

Table 13

Benefits Computation Results for the AIT Test Case

USING THE AIT AS A TEST BASIS, ASSUMING A SINGLE SQUADRON WITH TWO AIT SIMULATORS
THE TWO INTERFACES ARE: (a) AIT USED TOTALLY FOR INITIAL SKILL ACQUISITION
AND (b) AIT USED TOTALLY FOR MAINTENANCE OF THE SKILLS ONCE ACQUIRED

INPUT Names of Performance Areas	Performance Areas (i)	*INPUT* Continuation Use CUSE(i)	RANGE NAME	*INPUT* Necessity of Use NUSE(i)	RANGE NAME	*INPUT* Matrix of Values for Emulation Measures ESIM(i,j) Simulation Interfaces (j): ESIM(i,j) for Acquisition	RANGE NAME	ESIM(i,j) for Maintenance	RANGE NAME
Beyond-Visual-Range Employment - DC2	1	1.00	CUSE1	1.00	NUSE1	0.5500	ESIM11	0.5467	ESIM12
Radar Lookout - C	2	0.50	CUSE2	1.00	NUSE2	0.5167	ESIM21	0.4833	ESIM22
Tactical Formation - C	3	0.50	CUSE3	1.00	NUSE3	0.1867	ESIM31	0.1800	ESIM32
Two-ship Tactics - C	4	0.50	CUSE4	1.00	NUSE4	0.3667	ESIM41	0.2833	ESIM42
Four-ship Tactics - C	5	0.50	CUSE5	1.00	NUSE5	0.2500	ESIM51	0.0767	ESIM52
Radar Employment/Sorting - DC2	6	1.00	CUSE6	1.00	NUSE6	0.7500	ESIM61	0.6500	ESIM62
Tactical Intercept - DC2	7	1.00	CUSE7	1.00	NUSE7	0.7667	ESIM71	0.6667	ESIM72
Multibogey, Four or More - DC2	8	1.00	CUSE8	1.00	NUSE8	0.3917	ESIM81	0.3800	ESIM82

Performance Areas (i)	*INPUT* Aircraft Measures: Aircraft Sortie Time ATIME(i)	RANGE NAME	Aircraft Repetitions AREP(i)	RANGE NAME	*INPUT* Simulator Measures: Simulation Sortie Time Note: STIME(i) is held = ATIME(i) STIME(i)	RANGE NAME	Simulation Repetitions SREP(i,j,) SREP(i,j) Acquisition	RANGE NAME	SREP(i,j) Maintenance	RANGE NAME
1	1.50	ATIME1	2	AREP1	1.50	STIME1	6	SREP11	6	SREP12
2	1.00	ATIME2	1	AREP2	1.00	STIME2	1	SREP21	1	SREP22
3	1.00	ATIME3	1	AREP3	1.00	STIME3	1	SREP31	1	SREP32
4	1.00	ATIME4	1	AREP4	1.00	STIME4	1	SREP41	1	SREP42
5	1.00	ATIME5	1	AREP5	1.00	STIME5	1	SREP51	1	SREP52
6	1.50	ATIME6	2	AREP6	1.50	STIME6	6	SREP61	6	SREP62
7	1.50	ATIME7	2	AREP7	1.50	STIME7	6	SREP71	6	SREP72
8	1.50	ATIME8	2	AREP8	1.50	STIME8	6	SREP81	6	SREP82

Table 13 (continued)

"OUTPUT"

Simulation Benefit Factors

SBEN(i,j) = ESIM(i,j)*(SREP(i,j)/AREP(i))*(STIME(i)/ATIME(i))*(CUSE(i)*NUSE(i))

SBEN(i,j) Acquisition	RANGE NAME	SBEN(i,j) Maintenance	RANGE NAME
1.65000	SBEN11	1.64010	SBEN12
0.25835	SBEN21	0.24165	SBEN22
0.09335	SBEN31	0.09003	SBEN32
0.18335	SBEN41	0.14165	SBEN42
0.12500	SBEN51	0.03835	SBEN52
2.25000	SBEN61	1.95000	SBEN62
2.30010	SBEN71	2.00010	SBEN72
1.17510	SBEN81	1.14000	SBEN82

"OUTPUT"

NUM(i,j) is a function of the total number of simulation sorties designated by TOTNUM(j) (TOTNUM may be arbitrary or come from the NUMCALC spreadsheet) and the proportionate fractions (PROP(i,j)) generated by expert opinion.

Note that NUM(i,j) is a function of scheduling AND absolute throughputs achievable by the organizational alternative being evaluated.

NUM(i,j) = TOTNUM(j)*PROP(i,j)

NUM(i,j) per year

NUM(i,j) Acquisition	RANGE NAME	NUM(i,j) Maintenance	RANGE NAME
741.7872	NUM11	741.7872	NUM12
974.2656	NUM21	974.2656	NUM22
196.6272	NUM31	196.6272	NUM32
223.9776	NUM41	223.9776	NUM42
97.2048	NUM51	97.2048	NUM52
844.536	NUM61	844.536	NUM62
522.2448	NUM71	522.2448	NUM72
95.7264	NUM81	95.7264	NUM82
"INPUT"-> 3696	TOTNUM1	3696	TOTNUM2

"OUTPUT"

Aircraft
Use
Cost per sortie

MAC$(i)	RANGE NAME
$7,500.00	MAC$1
$5,000.00	MAC$2
$5,000.00	MAC$3
$5,000.00	MAC$4
$5,000.00	MAC$5
$7,500.00	MAC$6
$7,500.00	MAC$7
$7,500.00	MAC$8

"INPUT"

Proportion of the total sorties available in the organizational alternative which should be devoted to the Performance Area i. Note: This may also refer to a proportion of one sortie or some combination of sorties.

PROP(i,j) is proportion of sorties

	PROP(i,j) Acquisition	RANGE NAME	PROP(i,j) Maintenance	RANGE NAME
	0.2007	PROP11	0.2007	PROP12
	0.2636	PROP21	0.2636	PROP22
	0.0532	PROP31	0.0532	PROP32
	0.0606	PROP41	0.0606	PROP42
	0.0263	PROP51	0.0263	PROP52
	0.2285	PROP61	0.2285	PROP62
	0.1413	PROP71	0.1413	PROP72
	0.0259	PROP81	0.0259	PROP82
Sum of proportions for check purposes	1.0001		1.0001	

Table 13 (concluded)

"INPUT"

BENEFIT ELEMENTS	
Shadow cost of an aircraft per hour (SHADAC$)	$5,000.00
Cost of an aircraft (TOTAC$)	$51,116,000.00
Cost of the pilot (TOTPIL$)	$8,856,800.00
Probability of aircraft loss per flying hour (PLOSSAC)	0.0000306
Probability of pilot loss per flying hour (PLOSSPL)	0.0000205333

"OUTPUT"
Benefit Conversion Factors

Weapons Use Determined by task description and analysis WEAP$(I)	RANGE NAME	Loss of Aircraft AIRC$(I)	RANGE NAME	Loss of Pilot PILC$(I)	RANGE NAME
0	WEAP$1	$2,361.56	AIRC$1	$272.79	PILC$1
0	WEAP$2	$1,574.37	AIRC$2	$181.86	PILC$2
0	WEAP$3	$1,574.37	AIRC$3	$181.86	PILC$3
0	WEAP$4	$1,574.37	AIRC$4	$181.86	PILC$4
0	WEAP$5	$1,574.37	AIRC$5	$181.86	PILC$5
0	WEAP$6	$2,361.56	AIRC$6	$272.79	PILC$6
0	WEAP$7	$2,361.56	AIRC$7	$272.79	PILC$7
0	WEAP$8	$2,361.56	AIRC$8	$272.79	PILC$8

OVERALL BENEFITS IMPUTED TO THIS EXAMPLE

This matrix shows values for all component parts of each of the simulation interfaces

Each benefit element =
NUM(I,J)*(SBEN(I,J)*(MAC$(I)+WEAP$(I))+AIRC$(I)+PILC$(I)))

Since these values represent the final output of the computation, no range names are assigned to these locations

	Acquisition	Maintenance
	$12,403,924.67	$12,329,501.12
	$1,700,553.96	$1,580,628.46
	$124,011.65	$119,561.32
	$277,453.42	$214,351.12
	$82,092.28	$25,185.91
	$19,257,350.09	$16,689,703.41
	$12,173,534.28	$10,585,751.02
	$1,139,993.55	$1,105,942.17
TOTAL ESTIMATED BENEFITS	$47,158,913.90	$42,660,624.53

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